FEDERAL EXPERIMENT STATION IN PUERTO RICO
of the
UNITED STATES DEPARTMENT OF AGRICULTURE
MAYAGUEZ, P. R.

BULLETIN NO. 50

THE PRODUCTION OF LEMON-GRASS OIL

By
MERRIAM A. JONES and NOEMÍ G. ARRILLAGA

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MAYAGUEZ, P. R.

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STATION STAFF

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[1] In cooperation with the Government of Puerto Rico.

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By Merriam A. Jones and Noemí G. Arrillaga [1]

CONTENTS

INTRODUCTION

In 1935 a project was undertaken at the Federal Experiment Station in Puerto Rico with funds provided by the Government of Puerto Rico to investigate some of the crops from which essential oils are obtained. The present paper summarizes the experimental work with lemon-grass culture and processing. Information from our own experiments as well as from the available literature is presented.

Lemon grass has been found growing wild in many tropical areas such as the Malabar coast in East India, Ceylon, Malaya, French Indochina, West Indies, Central and South America, and in parts of Africa. Stapf (*67*) [2] described the plant in 1906 and outlined its history back to 1695. He stated that it seldom flowers and, to his knowledge, had never flowered in Java or Celebes. He also noted that distillation of the grass was recorded as early as the beginning of the seventeenth century in the Philippine Islands. The origin of the species was probably in India; it was introduced into Jamaica in 1799 and later into

[1] Merriam A. Jones was formerly Chemist, Federal Experiment Station, Mayaguez, P. R., and Noemí G. Arrillaga was formerly Collaborating Chemist in cooperation with the Government of Puerto Rico, Federal Experiment Station, Mayaguez.

[2] Italic numbers in parentheses refer to Literature Cited, p. 35.

other parts of the Americas and Africa (*67*). Only cultivated grass is now used for oil production.

A botanical distinction between two kinds of lemon grass is based on the properties of the oil produced from each type: (1) East Indian lemon-grass oil, which is distilled from *Cymbopogon flexuosus* Stapf, contains about 75 percent of citral, is soluble in 3 volumes of 70-percent alcohol, and is the principal type produced; and (2) West Indian oil, a commercial designation, is distilled from *C. citratus* (DC.) Stapf (fig. 1). This oil contains about the same proportion of citral but

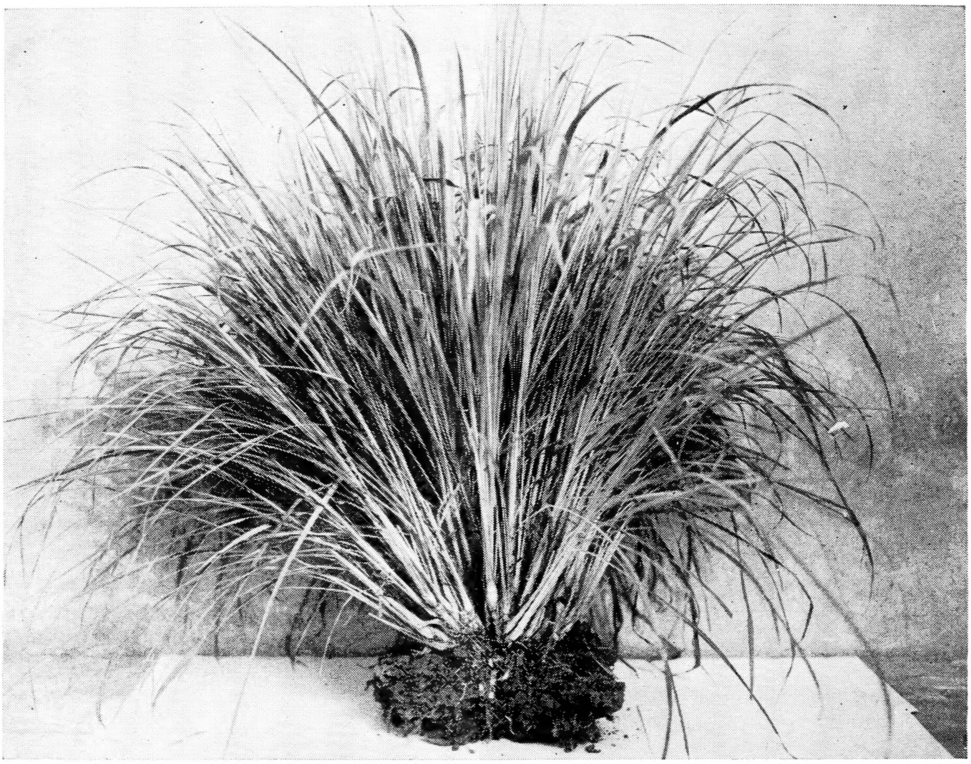

FIGURE 1.—A fully developed lemon-grass plant.

is less soluble in 70-percent alcohol. However, the distinction based on solubility in 70-percent alcohol is no longer important; citral content is the main consideration.

Lemon grass belongs to the Graminae family which also includes citronella grass, vetiver, and several other aromatic grasses. It is easily distinguished from citronella grass because the latter has a longer and narrower leaf. The lemon-grass leaf is about 3 to 5 centimeters wide. Britton and Wilson (*19*) describe lemon grass as a large, perennial grass with flat leafblades and with the spikelets in panicled racemes. The spikelets are in pairs, one sessile and the other stalked. The racemes are forked and bear an awnless, staminate spikelet in the fork. The sessile spikelet of the lower pair or pairs differs from those above. The culms are much branched, 1 to 2 meters tall, with the leaves crowded near the base. The inflorescence is decompound and up to 8 decimeters long. The leaves are glabrous, glaucous, and 6 to 10 decimeters long. The spathes are lanceolate and the racemes 1 to 1.5 centimeters long, with the sessile spikelet linear to linear-lanceolate, acuminate with the back concave below. The nodes of the culm are ceriferous, and the branches of the inflorescence elongated and somewhat pendulous.

Although the principal use of lemon grass is for the production of lemon-grass oil by distillation, minor uses have been reported for the plant material itself. Thus, a small amount of grass is used for woven articles, home preparation of dentifrices and sedatives, and as a condiment. The roots of lemon grass have also been used for similar purposes (*23*); the oil therein is about 82-percent citral (*1*). Alluaud (*4*) states that lemon grass as well as citronella grass repels the tsetse fly.

The spent grass removed from the still after distillation of the oil is used as a mulch and in compost preparation. In Florida it was used in the preparation of a cattle feed (*14*, *16*, *17*, *18*). Some work has been done on the use of lemon-grass residue for the manufacture of paper.

The oil distilled from lemon grass has many minor uses. Thus, Bacon (*12*) pointed out that the oil can be used to improve the flavor of stale fish, and to flavor wines, sauces, candies, and spices. As an external agent he reported it useful for headache, toothache, and for baths and fomentations, particularly in female complaints. Although the oil is said to be efficacious against cholera, it is not useful as a bactericide (*56*). The oil has been used to lend a clean smell to hospital rooms and closets. Other uses are as a sudorific and diuretic agent for fever and for bilious conditions (*30*). Lemon-grass oil can cause a dermatitis. This result has been noted at this station and was also reported by Mendelsohn (*47*), who treated the ailment successfully with a soothing antipruritic lotion and a bland ointment.

More important uses for lemon-grass oil are: As a perfume for inexpensive soaps, as a flavor, and as a source of citral. Citral is separated from the oil for the manufacture of ionone, which is known as synthetic violet in the perfume trade. Citral has further uses as a raw material in the synthetic chemical industry.

Before World War II the United States imported lemon-grass oil from Madagascar, Malabar, Travancore, Cochin, Ceylon, and Java. The annual world production was about 300 to 350 tons. Since 1930, sources of lemon-grass oil have been developed in the Western Hemisphere. Some lemon-grass oil was produced in Florida. The crop was established there to utilize labor during the off-season of the sugar industry, but the annual production of oil did not exceed 35,000 pounds which was produced in the fiscal year 1943–44. In Honduras the United Fruit Co. has undertaken production of the oil; production was begun in Guatemala in the early 1930's and has grown to about 185,000 pounds which was exported to the United States in 1944. Comparatively small producers are located in the Dominican Republic, Haiti, El Salvador, and Puerto Rico.

There is no protective tariff in the United States for lemon-grass oil but there is an ad valorem duty of 75 percent on citral. Table 1 gives the imports of lemon-grass oil into the United States.

Between 1942 and 1945 the price of lemon-grass oil fluctuated between $0.64 and $4.50 per pound; war conditions, however, affected these prices. Before the war, the price, although as low as $0.30 per pound, was usually from $0.60 to $0.80. During the war years the importation into the United States increased greatly from the Latin-American countries.

TABLE 1.—*Imports for consumption of lemon grass oil into the United States, 1937–49, inclusive* [1]

Country	1937	1938	1939	1940	1941	1942	1943
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Canada	0	0	0	0	0	4, 050	0
Argentina	0	0	0	0	0	0	0
Brazil	0	0	0	25	1, 127	2, 466	0
Dominican Republic	0	0	0	0	0	107	432
El Salvador	0	0	0	0	0	858	1, 145
Guatemala	85, 371	29, 500	63, 915	116, 229	139, 751	164, 423	190, 542
Haiti	0	0	0	0	0	9, 257	10, 041
Honduras	0	0	0	0	0	2, 537	19, 700
Mexico	0	0	0	0	0	123	1, 488
France	8, 932	2, 054	75	49	0	0	0
Germany	0	200	1, 150	0	600	0	0
Netherlands	1, 060	921	1, 392	200	0	0	0
United Kingdom	74	0	0	500	0	0	0
Belgian Congo	0	0	0	0	0	0	0
British East Africa	6, 678	0	0	0	0	0	0
Madagascar	0	7, 373	400	0	0	0	11, 063
Ceylon	0	0	0	0	17, 920	53, 567	0
French Indochina	0	0	0	0	4, 480	0	0
India and Dependencies	251, 501	287, 613	463, 814	263, 228	548, 660	496, 962	178, 304
Net quantity	353, 616	327, 661	530, 746	380, 231	712, 538	734, 350	412, 715
Value in dollars	125, 443	107, 702	171, 203	194, 612	583, 916	1, 442, 305	411, 331

Country	1944	1945	1946	1947	1948	1949
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Canada	0	0	0	0	0	0
Argentina	0	0	0	1, 000	0	0
Brazil	4, 410	1, 800	24, 478	1, 124	16, 348	14, 554
Dominican Republic	1, 242	4, 614	3, 580	3, 662	1, 000	0
El Salvador	4, 504	6, 056	9, 020	6, 977	13, 099	10, 868
Guatemala	184, 908	109, 265	109, 423	129, 977	142, 333	116, 596
Haiti	8, 475	14, 208	29, 716	37, 695	80, 692	56, 171
Honduras	11, 600	9, 123	2, 735	3, 258	411	0
Mexico	1, 058	0	9, 655	5, 869	66	4, 128
France	0	0	0	0	0	0
Germany	0	0	0	0	0	0
Netherlands	0	0	0	0	0	0
United Kingdom	0	0	0	0	0	0
Belgian Congo	0	1, 093	1, 407	4, 662	21, 796	800
British East Africa	0	2, 773	4, 209	0	11, 412	6, 425
Madagascar	0	0	0	0	8, 317	0
Ceylon	0	0	0	3, 136	0	0
French Indochina	0	0	0	0	0	0
India and Dependencies	812, 321	1, 147, 720	732, 522	432, 988	206, 128	419, 560
Net quantity	1, 028, 518	1, 296, 652	917, 745	630, 348	501, 602	629, 102
Value in dollars	916, 525	1, 971, 903	2, 343, 082	1, 233, 044	525, 945	806, 353

[1] Department of Commerce.

CULTURE

CLIMATE

Lemon grass grows best in a tropical climate. Although the plant has been grown successfully in cooler climates where frosts sometimes occur, such as in southern Florida, southern Italy, Sicily, and northern Argentina, the greatest yields are obtained in the Tropics. Lemon grass has been grown at elevations of 3,000 feet in East Africa (*73*, *74*), sea level to 5,000 feet in Ceylon (*23*), but Jowitt (*42*) reported that, on poor soil at 4,500 feet in Ceylon, cultivation was unsuccessful. Rutowski and Winogradowa (*58*) report that lemon grass has been grown in the Caucasus since 1906. The plant withstands severe drought, but makes practically no growth under such conditions. Under very arid conditions the leaves become dry and shriveled before the roots die. The field in this condition is often burned to save the roots; then when rain comes, the roots develop and new leaves appear.

If irrigation is not used, the rainfall should be at least 60 inches per annum. In Haiti where 35 to 60 tons of grass per acre per year are produced, irrigation is highly successful. Irrigation has also been successful in a very dry district in Sicily; the yield of oil was doubled by an unspecified amount of irrigation (*21*). In Amani, East Africa, Worsley (*74*) attempted to correlate climate and yield in his plantings. He found a very rough positive correlation between the amount of rainfall and the citral content of the oil but could not correlate other data.

SOIL

Sandy loam and light sand have given good results but cultivation on heavy clay is not successful. The use of poorly drained soil results in stunted growth and the development of purple coloration in the leaves. If a planting shows these symptoms and the water table is high, a trial drainage should be effected by running ditches 2 feet deep at 50-foot intervals in part of the planting. Improvement should be noticeable within several weeks.

The nutrient requirements of lemon grass are similar to those of most grasses in that potassium and nitrogen are important. It is often pointed out that lemon grass is a thrifty crop and hence can be grown on waste land or very poor soil; however, like most crops, it responds to good soil and fertilization and the net result of fertilization is more economical production of lemon-grass oil. Whether a good soil and a large quantity of fertilizer are to be used on lemon grass is a question of practical agriculture.

Fertilizer can be applied to lemon grass at the time of planting by placing it in the holes in which the grass is to be planted and covering it with an inch or two of soil. The fertilizer may be broadcast and hoed or disked in but this tends to encourage weeds among the lemon-grass stools. Hood (*37*) showed that, on Florida sandy soil, lemon grass required somewhat more potash than did some other grasses. Analysis showed that 10,000 pounds of lemon grass contained 20.32 pounds of nitrogen, 33.20 pounds of potash (K_2O), and 18.75 pounds of phosphoric acid (P_2O_5). Better growth was obtained when potash was applied as the sulfate and when part of the nitrogen was organic. A 4–5–8 fertilizer applied at the rate of 600 pounds per acre gave optimum resuts under such conditions.

Dawe (*23*) cited analyses obtained in Ceylon which showed that 10,000 pounds of fresh grass contained 65 pounds of potash, 12 pounds of nitrogen, 12 pounds of lime (CaO), and 9 pounds of phosphoric acid. On poor sandy soil in Florida, Russell (*57*) approximately doubled the yield of grass and oil by using 300 pounds per acre of a mixture made up of 15 parts of acid phosphate, 4 parts of dry tobacco stems, and 5 parts of sodium nitrate. Analysis of lemon-grass ash from Sicily showed 6.64 percent of potash, 0.90 percent of nitrogen, 5.45 percent of iron oxide, 14.97 percent of phosphoric acid, 7.70 percent of sulfur (SO_3), 36.90 percent of silica (SiO_2), and 4.20 percent of chlorine (*20*). It is calculated that each hundredweight of grass removed from the soil 153 grams of potash, 345 grams of phosphoric acid, 167 grams of nitrogen, and 389 grams of lime.

Beckley (*13*) recommended the use of at least 15 tons of compost and 200 pounds of potassium sulfate per acre before planting. The compost was prepared from lemon grass that had been exhausted of oil by distillation. He spread 6-inch packed layers of spent grass, contaminated it with soil, and added to each ton of compost 50 pounds of a mixture of (1) 4 parts of ammonium sulfate, 5 parts of superphosphate, and 6 parts of ground limestone, or (2) 4 parts of ammonium sulfate and 10 parts of bone meal, guano, or ground rock phosphate. The compost pile was kept moist for several months until it was well rotted and ready for use.

Luisi (*46*) in Italy compared the results obtained in plots fertilized with inorganic materials with those fertilized with both organic and inorganic materials. Over a period of 3 years the inorganic treatment consisted of the application of 3,256 pounds per acre of ground acid phosphate rock, 1,346 pounds of ammonium sulfate, 706 pounds of potassium chloride, and 1,445 pounds of gypsum. During the same period the other plots received 1,052 pounds per acre of dried blood, 2,464 pounds of acid phosphate rock, 378 pounds of potassium chloride, 1,445 pounds of gypsum, and 422 pounds of calcium nitrate. The plots were irrigated at intervals of 8 to 10 days from May to October.

From the plots treated with inorganic material, the acreage production in 3 years was 165,321 pounds of grass yielding 249.1 pounds of oil. The corresponding figures for the combined treatment were 145,797 pounds of grass yielding 228.3 pounds of oil. Bourne (*16*) reported that an application of 200 pounds of potassium chloride (60 percent K_2O), 200 pounds of ammonium sulfate (20.5 percent nitrogen) per acre to Florida willow-elder peat soil was most beneficial to the soil and gave the best yields of lemon-grass oil. A very marked response to potash was obtained on these sandy soils.

With only a light covering of barnyard manure at the time of planting, a lemon-grass plot at Mayaguez produced at the rate of 51 tons of grass or 312 pounds of oil per acre per year. Four harvests were made during the year. This plot was on a hillside of Catalina clay.[3]

In a fertilizer experiment at the Federal station the effectiveness of nitrogen alone and in combination with phosphoric acid, potash,

[3] Roberts (*55*) described Catalina clay as "one of the red friable clay soils distributed over the ridges and slopes in areas receiving more than 79 inches average annual rainfall and where the most-important soil-forming rocks are andesitic tuff and tuffaceous shale. * * * This soil is deficient in lime, phosphorous and magnesium."

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and lime was determined (*53*). The rate of application was 100 pounds per acre of each constituent. The results for four harvests are shown in table 2.

TABLE 2.—*Yields per acre per year*[1] *of lemon grass, oil, and citral for 6 fertilizer treatments*[2]

Treatment	Grass	Oil	Citral
	Pounds	*Pounds*	*Pounds*
None	35, 109	135	94
N	39, 783	149	105
NPCa[3]	41, 722	172	128
NK	60, 169	244	183
NPKCa	51, 291	239	160
NCa	38, 769	157	108

[1] Four harvests were made during the year.
[2] Fertilizer applied in furrows and covered before planting.
[3] When phosphate was included, calcium was also applied because the phosphate was applied as calcium superphosphate.

All treatments in which fertilizer was applied were superior to that in which none was used. Yields were increased by about 70 percent by the use of only 100 pounds each of nitrogen and potash per acre per year.

The value of nitrogen as a fertilizer constituent for lemon grass was further demonstrated in an experiment carried out at Mayaguez (*53*). The final results of this experiment, which were not published, are summarized in table 3. In this trial only potash, 40 pounds per acre, was supplied along with different amounts of nitrogen applied as ammonium sulfate. The table shows that the use of about 200 pounds of nitrogen per acre resulted in an increase of about 100 pounds of oil. The increase was due to the grass being richer in oil. The grass yield did not increase in proportion to the oil yield.

TABLE 3.—*Yields per acre per year*[1] *of lemon grass, oil, and citral as affected by different amounts of nitrogen fertilizer*[2]

Nitrogen (pounds per acre)	Grass	Oil	Citral
	Pounds	*Pounds*	*Pounds*
0	101, 203	373	253
60	106, 333	412	303
120	107, 156	432	319
180	111, 305	475	325
240	117, 561	461	338

[1] 4 harvests were made during the year.
[2] Fertilizer was applied in furrows and covered before planting.

Although lemon grass responds markedly to fertilization with nitrogen and possibly potash, the question of whether optimum results can be obtained with or without these amendments must be answered by the individual producer. No general recommendations can be made; the value of a given fertilizer constituent depends to a great extent on the soil on which the crop is being grown. However, on soil that is not extremely poor, several hundred pounds each of ammonium sulfate, high potash fertilizer, and compost or manure per acre could be used to good advantage.

LIGHT REQUIREMENTS

The feasibility of using lemon grass as a catch crop depends to a great extent upon the response of the grass to shade. Lemon grass interplanted with tree crops would be shaded more and more as the trees increased in size. In Ceylon the grass is interplanted with rubber with the result that returns on the land can be obtained from

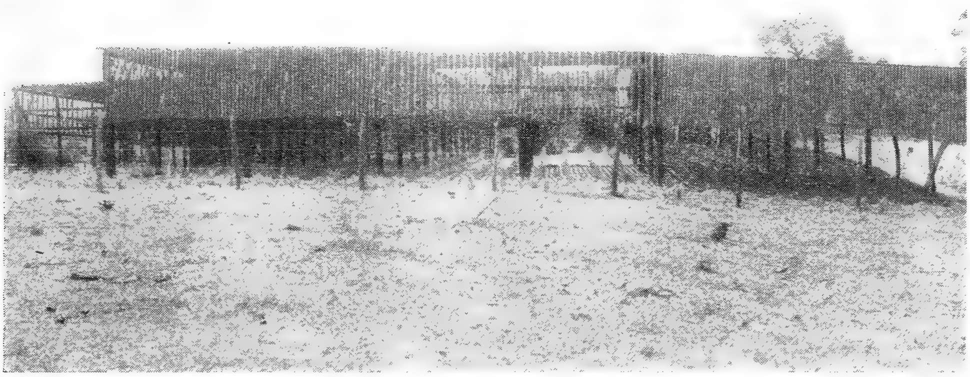

FIGURE 2.—Lath shelter used to determine the response of lemon grass to amount of sunlight. The strips are spaced so that some plots receive two-thirds of the sunlight and others receive one-half or one-third. Control plots not under the shelter receive full sunlight.

the lemon grass long before the rubber comes into production. Serre (*62*) reported in 1905 that plants growing in the sun do not live as long as those in the shade but that the oil in the sun-grown plants contains more citral. No yield data were given. Squibbs (*63*) reported in 1938 that the highest yield obtained in Seychelles was 2.2 liters of oil per ton of grass grown in the shade of coconut trees, whereas from sun-grown plants 3.2 to 4.2 liters of oil per ton of grass were produced.

The results of an experiment at this station in which lemon grass was grown under different degrees of shade are given in table 4 (*11*, *70*). Figure 2 shows a lath frame which was used for controlling the amount of sunlight. It is clear that shade decreased the productivity of lemon grass considerably. Therefore, as an intercrop, lemon grass should be grown with crops that will not shade the grass to a great extent for 4 or 5 years. When the tree crop reduces the sunlight by as much as one-half, the yields from the lemon grass can be expected to decrease by one-half.

TABLE 4.—*Yield of grass, oil, and citral from four harvests of lemon grass under different intensities of sunlight*

Treatment	Grass		Oil			Citral		
	Moisture content	Yield per acre	Yield	Specific gravity	Calculated amount per acre	In oil	In grass	Calculated amount per acre
	Percent	*Pounds*	*Percent*		*Pounds*	*Percent*	*Percent*	*Pounds*
Full sunlight	76. 21	80, 890	0. 313	0. 882	253	67. 73	0. 212	171
Two-thirds sunlight	80. 44	58, 019	. 291	. 885	169	74. 22	. 216	125
One-half sunlight	82. 42	43, 280	. 278	. 886	120	72. 66	. 202	87
One-third sunlight	88. 46	28, 534	. 268	. 892	76	73. 51	. 197	56

PROPAGATION

Lemon grass, a stoloniferous grass, is propagated by division of clumps; it does not ordinarily produce seed unless grown without being cut for several years in a suitable climate. Figure 3 shows a lemon-grass stool divided for planting. The leaves are cut back to about 3 inches. It is possible to obtain as many as 50 new stools from one old clump. After the field has been prepared by the required plowing and disking, the bud pieces are planted in holes 2 to 3 feet apart. In Amani, Worsley (*74*) found that planting in rows 9 inches apart and 9 inches apart in the row gave grass yields 10 times as great and oil yields 7 times as great as did planting in rows 3 feet apart and

FIGURE 3.—The division of a lemon-grass stool into pieces for propagation: *a*, whole stool after the removal of leaves; *b*, part of the stool in the process of being divided; *c*, one of the many "seed pieces" obtained.

3 feet apart in the rows, but his data were obtained in different years on different soils. At Mayaguez the practice has been to plant 4 bud pieces to the hill at intervals of 18 inches in rows 32 inches apart. Whether planting as well as other operations should be mechanized depends on the cost of labor in the area. Like sugarcane, lemon grass is a perennial and can be harvested in ratoons but at some age, probably from 4 to 8 years depending on conditions, the planting becomes so much less productive that the fields must be replanted.

Large plantings are usually on level land especially if mechanical devices are to be used. However, lemon grass can be grown on hillsides and has been highly recommended as a crop for soil conservation. For this purpose lemon grass can be used like other grasses such as Guatemala or molasses grass. The grass can be planted on slopes up to 40 percent. Figure 4 shows lemon grass on a steep hillside in Puerto Rico. A single row is planted at 1-foot intervals on contours which differ by a 6-foot vertical rise. After the grass is established, and thereafter after each harvest, the soil just above the grass is plowed so as to turn it onto the grass stools. During the course of about 3 years, bench terraces will be formed by this process of plowing and the washing by rains. During and after this time of forming the terraces, the level parts can be planted with lemon grass or with vegetables or other plants. Later, lemon grass can be grown on the slopes as well as on the edges of the terraces. By such practice, erosion

FIGURE 4.—Trial planting of lemon grass on a steep hillside provided with contour ditches.

losses can be decreased to less than 1,000 pounds of soil per acre per year. At this rate erosion is no problem because the rate of formation is generally greater than the losses of soil. Lemon grass can also be planted in rows above hillside drainage ditches to decrease the amount of soil being washed into the ditches.

HARVEST

To harvest lemon grass, the plants are generally cut to within 3 inches of the base of the clump. It was reported (*59*) that the oil from the flowers of lemon grass contained 79 to 83 percent of citral, whereas the oil from the leaves contained 81 to 86 percent. Hood (*37*) cited tests in which the yield and the citral content of lemon-grass oil were determined in the lower, middle, and upper portions of the leaves. The upper third of the leaves gave 0.46 percent of oil containing 70 percent of citral, the middle third 0.24 percent of oil containing 78 percent of citral, and the lower third 0.10 percent of oil containing

82 percent of citral. These findings indicate that the lower portion of the grass was hardly worth harvesting for oil, but the yield of grass should also have been considered. Naves and Auriol (*50*) found that the upper part of the plant contained 0.6 percent of oil, whereas the lower part contained only 0.125 percent.

Squibbs (*63*) reported from Seychelles that the highest yields from grass excluding the base of the plant were 2.2 liters of oil per ton of grass, whereas from the bases 1.5 liters of oil per ton of grass were obtained. It should be noted that these data represent highest yields obtained rather than mean yields. Rakshit (*54*) carried out distillations in which a 0.34-percent yield of oil containing 85 percent of citral was obtained from the upper part of the plant, whereas the lower part yielded 0.23 percent and contained 95 percent of citral. Here again no account was taken of the weights of the grass in each part of the plant.

At the Federal Experiment Station a similar experiment was made wherein the weights of the grass were also considered (*8*). Lemon grass 3 to 4 feet high was cut about 3 inches from the clumps and divided into the lower, middle, and upper thirds. The data showed that, although the percentage of oil was lowest for the bottom part, the weight was 66.3 percent of the total, and, therefore, the yield of oil per 100 pounds of whole grass was highest in the lowest portion. The citral content was highest in the bottom part of the grass. About one-half of the oil and citral was in the lower third of the grass. Therefore, the grass should be cut short but, of course, not less than 3 inches from the clump lest subsequent growth be retarded.

Microscopic examination of lemon grass was made to determine whether the oil in the grass was contained in solution or in vacuoles of cells or in glands. Sections were examined to determine whether differences among the top, middle, and bottom portions would account for the facts noted in the foregoing paragraphs (*52*). It was found that the oil existed in secretory cells and oil glands as shown in figure 5. In the lower part of the leaf there were few cells, but these were relatively large and further removed from the point of exudation. The middle portion contained more cells of smaller size closer to the edge of the leaf. The top section had even more cells which were yet smaller in size and closer to the point of exudation. It appeared that the size of the cells was correlated with the quantity and quality of oil; the large cells which contained more oil were more developed and were in the region where the oil obtained contained a higher proportion of citral.

In areas where labor is cheap and plentiful, lemon grass is produced by hand labor from the clearing of the land to the loading of the still pot. The degree of mechanization increases as labor is more expensive or less available and as the size of the plantation increases. The most highly mechanized production was probably at Clewiston, Fla., where the U. S. Sugar Corporation had a large lemon-grass project (*16*). A view of their planting is shown in figure 6. There, labor is scarce and high-priced; without mechanical appliances, lemon grass would not be grown. The degree of mechanization is less in Guatemala, Honduras, and in the West Indies. Mechanization may begin with clearing the land and planting the grass. Cultivation as necessary during the first year can also be carried out with tractors and suit-

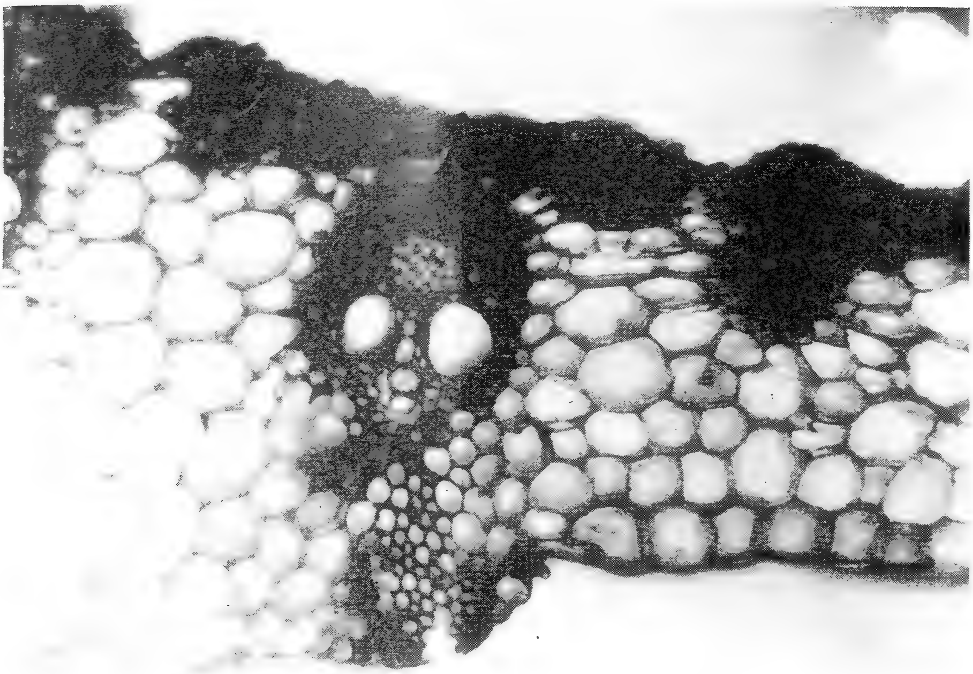

FIGURE 5.—Cell structure of lemon grass.

FIGURE 6.—Lemon grass near Clewiston, Fla. The distillery is in the background.

able cultivators. At Clewiston harvesting was done by tractor-drawn cutters that loaded the grass on special wagons each fitted with a basket which held 1½ tons of fresh grass. The wagons were then drawn to the processing center and unloaded by means of a crane. The apparatus is shown in figure 7. Harvesting could also be done by using hay cutters and hay rakes to gather the grass. Russell (*57*) states that mowing lemon grass is a satisfactory practice but that much grass is lost in raking; he therefore recommends a reaper. No

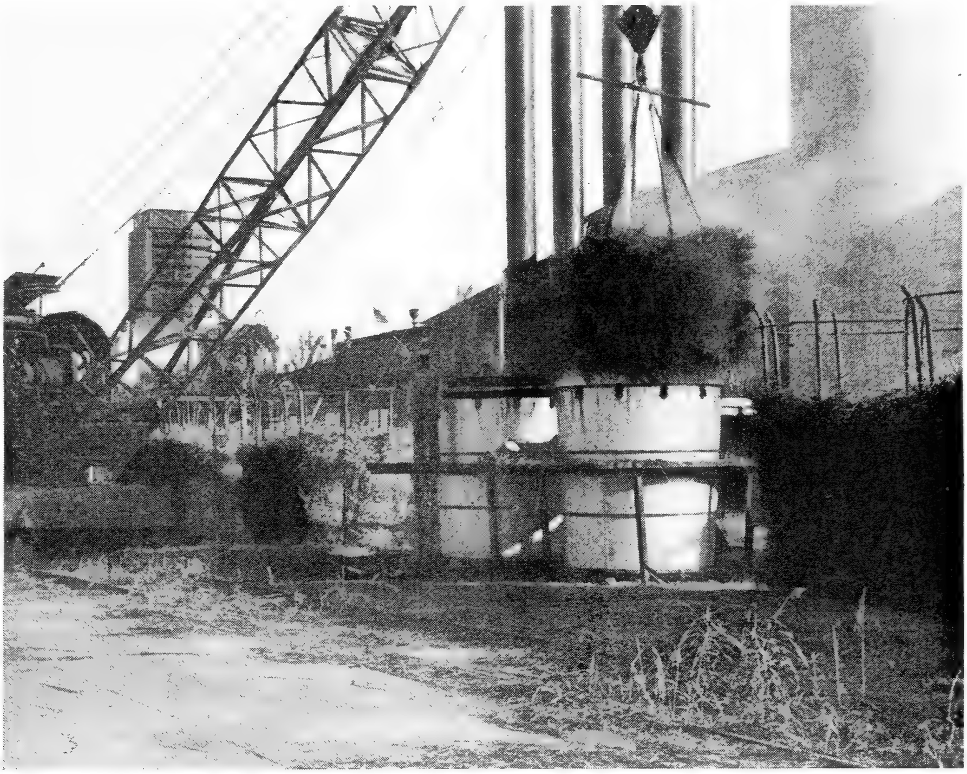

FIGURE 7.—Lemon grass shown being unloaded for processing at Clewiston, Fla.

doubt many other types of standard farm machinery could be applied to lemon-grass production.

The frequency of harvests determines to a great extent how much oil can be produced from lemon grass per acre per year. It is generally recommended that the grass be cut 5 to 9 months after planting, at which time the plants should be 2½ to 3 feet high and the bunches 8 to 10 inches in diameter. Thereafter harvest can be made 3 or 4 times a year. Wright and Bamber (*75*) in Ceylon estimated that an average yield of 5 tons per acre containing 20 pounds of oil could be obtained in 3 cuttings per year. Watts and Tempany (*71*) estimated 9 to 12 tons of grass per acre per year in 2 or 3 harvests in the West Indies. This would amount to 36 to 60 pounds of oil per acre per year. Bacon (*12*) pointed out the variation in yield estimates given by different authors. These estimates ranged from 20 to 260 pounds of oil per acre per year. In Java (*1*) it was recommended that lemon grass be harvested when the fifth leaf is well developed.

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A report from the Fiji Islands describes an experiment which showed that the most oil was obtained when the grass was cut at the flowering stage (*27*). Dawe (*23*) estimated a yield of 9 tons of grass containing 70 pounds of oil in Ceylon. Bruno and Sorges (*20*) considered 88 pounds of oil per acre per year could be obtained in Sicily if the grass were cut when over 3 feet high. Beckley (*13*) estimated that in Kenya Colony 120 pounds of oil per acre per year could be obtained. In East Africa, Worsley (*74*) obtained 33 to 238 pounds of oil per acre in 10 harvests made during the year. From Florida, Bourne (*16*) reported a yield of 150 pounds of oil per acre from 3 harvests made during the summer. In another Florida report, it was estimated that 1,000 acres should yield a ton of oil per month (*3*). Mutinelli (*48*) in Argentina estimated 8 to 12 tons of grass per acre

FIGURE 8.—Lemon-grass plots at several stages of development at the Federal Experiment Station in Puerto Rico.

could be obtained in 2 to 3 harvests per year. This would be equivalent to 40 to 70 pounds of oil per acre per year.

At the Mayaguez station trials were made to determine the optimum interval of harvests (*52*). Figure 8 shows a field of lemon grass with plots at different stages of growth. Plots were cut at 12, 15, 18, and 21 weeks of growth for 2 years, and the results were calculated on the basis of return per acre per week. Table 5 shows the summary of the experiment. This experiment showed that, from the standpoint of grass or oil per unit area per unit time, a harvest every 21 weeks produced the best results.

Since growth during the interval between harvests is obviously affected by climatic conditions, another experiment was made to find the optimum height at which lemon grass should be harvested (*60*, *61*). In this study, plots were cut at 2 feet, 2½ feet, and at maximum growth to determine at which height maximum returns would be realized. Maximum growth was taken as the height at which no apparent leaf elongation occurred over a period of 4 weeks; this was generally 3 to 3½ feet. The results over the first 2 years of growth for 2 varieties are shown in table 6.

TABLE 5.—*Effect of interval between harvests on yields per acre per week of lemon grass, oil, and citral*

Interval of harvest (weeks)	Grass	Oil	Citral
	Pounds	*Pounds*	*Pounds*
12	942	3. 0	2. 1
15	1, 077	3. 4	2. 4
18	1, 179	3. 5	2. 3
21	1, 213	3. 6	2. 4

TABLE 6.—*Yields per acre of lemon grass, oil, and citral from grass cut at 3 heights over a 2-year period*

Height at harvest (feet)	Harvests	Yields		
		Grass	Oil	Citral
JAVA VARIETY				
	Number	*Pounds*	*Pounds*	*Pounds*
2	10	79, 139	211	158
2½	10	99, 596	329	251
3 to 3½	6	102, 019	266	202
WEST INDIAN VARIETY				
2	10	73, 217	239	175
2½	10	75, 774	286	219
3 to 3½	6	75, 639	237	180

The trials showed that the greatest oil yield per acre was obtained when the grass was cut at 2½ feet. However, more oil per harvest was obtained when the grass was cut at maximum height. Therefore, it becomes a question of economics whether the grass should be cut at 2½ feet or at maximum height. If the profit margin is great compared to the cost of production of grass, the grass should be cut at 2½ feet. On the other hand, if the profit margin is small, the cost of production should be kept low by cutting at maximum height. It was noted that the plants cut at 2 feet had a high mortality; those which grew after harvest did not expand as did those cut at greater heights. Best growth was observed at the beginning of the rainy season.

For best results some essential-oil-bearing plant materials require treatment prior to distillation. For example, orris and vetiver root should be dried before distillation and it has been recommended that citronella grass be dried to some extent before distillation. Drying offers certain advantages, such as more efficient use of stills, labor, and available fuel and steam. Hood (*37*) pointed out that lemon grass lost a considerable amount of oil during drying. An experiment on drying was performed at this station (*10*), in which grass was distilled (1) fresh, (2) after field drying, and (3) after being stacked for a month. Field drying of the grass resulted in a loss of 22 percent of the oil, whereas storage of the grass by stacking resulted in the loss of half the lemon-grass oil. Analyses of the oil showed that most of the loss was citral. Although hauling costs would be reduced by these practices, the severe oil losses would make them impractical.

Methods of moving the grass from the field to the processing area vary from the most primitive, such as employed by natives in Ceylon, to the most modern, employed at the Clewiston project. A novel method suggested by Atherton Lee for use in the United Fruit Co. plantings in Honduras is to flume the grass. In this practice the grass would be raked or otherwise transported to canals or chutes. A fairly swift current of water would then carry the grass to the still where it would be caught on screens and processed. At this station, trials were made in which grass was immersed to simulate transportation in water. The effects of soaking lemon grass in water on the yield of oil are shown in the accompanying tabulation.

Treatment:	*Percent*
Grass cut fresh and distilled whole	0.19
Grass cut fresh, soaked in cold water ½ hour, and distilled whole	.17
Grass cut in the feed cutter and distilled fresh	.24
Grass cut in the feed cutter, soaked in cold water for ½ hour, and distilled	.23

It is clear that, since the oil loss was negligible, the practice may be feasible where sufficient running water is available and flumes can be constructed to lead the grass to a processing area on a lower level.

INSECTS AND DISEASES

Fletcher (*29, p. 79*) noted that lemon grass is an alternative food plant for the sugarcane borer, *Sesamia inferens*. Fritz (*31*) reported that in Madagascar a beetle, *Heteronychus plebejus*, attacks freshly planted lemon grass as well as sugarcane. He also noted a disease marked by patches at the end of the leaves which were brown at first but later became reddish. Chalot (*22*) reported that in French Guinea in Africa a fungus develops around the base of the plant and finally debilitates the clump to the point of death. He also stated that an unnamed beetle gives trouble because its larva pierces the thicker lower part of the leaves and causes eventual death of the plant.

Lemon grass is sometimes infested by the aphid, *Sipha flava* Forbes, which causes the grass to become reddish brown and very dry. Distillation of the infested grass showed that, although the yield of oil was somewhat lower, the infestations did not markedly affect the quality of the oil. In Haiti, slight attacks have been reported of an undetermined insect whose larvae rolls the leaf sheaths of the lemon grass. Probably the worst infestations reported have been those in Guatemala. In Puerto Rico infestations have been found of the sugarcane borer, *Diatraea saccharalis* (F.), but damage has never been serious.

Bourne (*15*) reported an eyespot disease of lemon grass in Florida. He was able to prove that the lemon grass and sugarcane eyespot disease is caused by the same *Helminthosporium* organism. The lesions of the disease are similar to those in the same disease infesting sugarcane, except that no red color appeared on the lemon grass as it did on sugarcane. Typical spots appear at first as minute yellowish flecks with a rusty brown center. The spots grow, and when 6 mm. long along the axis of leaf by 2 mm. wide, an oval portion becomes a light flesh or straw color, outside of which is a dark purple, narrow, oval border surrounded by a somewhat oval zone, Spanish-raisin in color. This is surrounded by a yellowish to flesh-colored aureola. The spots are often elongated at both ends and when full size are 1.5 to 2 mm. by 4 to 10 mm. Often the spots coalesce to form irregular blotches. Control of this disease is best effected by removal of infested plants to prevent infestation of the whole planting.

In 1941, Dodge (*24*) noted in Guatemala a severe attack of *Helminthosporium* spot on lemon grass and citronella grass. Irrigation and moist conditions led to high humidity conditions. A leaf spot and a *Fusarium* sp. attacked the base of the plant. He stated that the leaf spot starts as a small yellowish area between veins and grows to an elliptic-shaped area with reddish margin like a similar condition in sugarcane. The central portion then becomes brown and dry and the distal portion of the leaf dies. Saprophytes, such as *Hormodendrum*, may then invade dead parts. He named the organism *Helminthosporium Cymbopogi*, sp. nov. He recommended control by means of spraying bordeaux mixture or a lime-sulfur dust. This means of control is, of course, expensive. To determine whether resistant plants could be selected, Dodge replanted some plants which had remained healthy in an infested area; but about half of these were diseased when they developed.

Since spraying procedures are in general too expensive to use in an attempt to control diseases of the plant, the only practical countermeasures against these diseases consist in maintaining the vigor of the planting by suitable agronomic practices and by removing infested plants. Considerable relief from fusarium infestation was obtained in Guatemala by installing drainage that lowered the water table in the planting.

PROCESSING

EQUIPMENT

Steam distillation is employed to obtain the oil from lemon grass. The details of this process vary according to the apparatus used, but the principle involved is to distill water from a suspension of grass in water or to pass steam through the grass so that steam and essential oil vapor will pass into a condenser, liquefy, and then separate in a receiver as a result of their mutual immiscibility.

The equipment used is similar to that used for the distillation of other essential-oil-bearing plant material (*33*, *64*). Older equipment consisted of a large vat heated by a fire. The condenser was generally a long copper coil, perhaps 2 inches in diameter and 60 feet long, suspended in a large vat of cooling water (*75*). This type of equipment gives good results and is still in use, but it has two serious disadvantages: (1) There is some decomposition where oil or plant residue comes in contact with overheated metal in the region of direct-flame heating; and (2) the distillation is exceedingly slow, which increases its cost. For these reasons, it is better to heat by steam generated in a separate boiler. The steam can be used to furnish heat by passing it through a closed coil in the still pot or through a jacket enveloping the still pot. Or, the steam can be used to cause movement of vapors as well as to transmit heat by passing it through a perforated

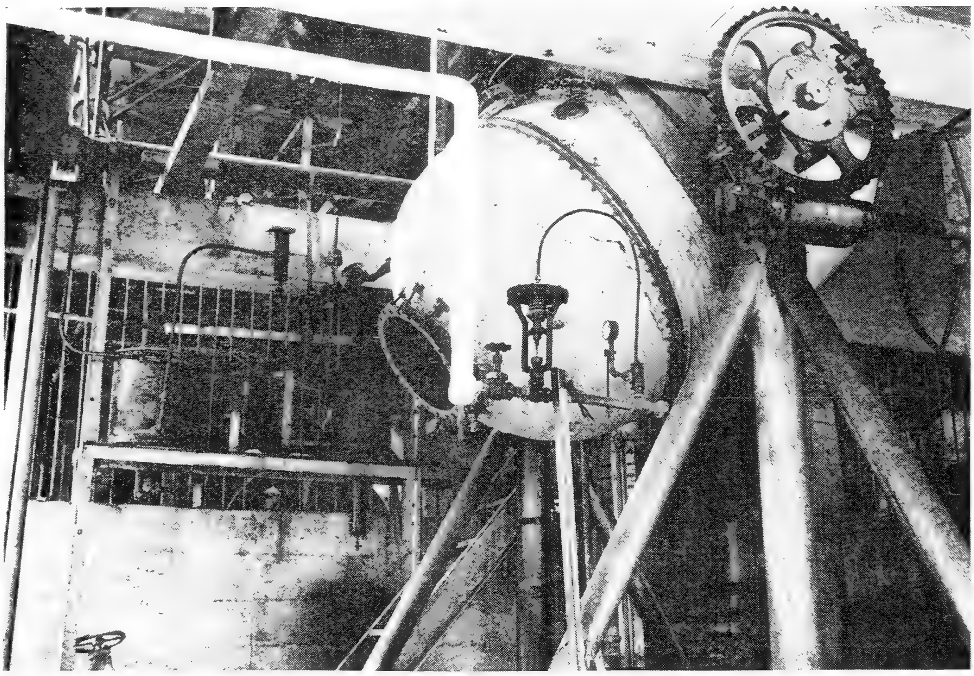

Figure 9.—General view of an essential oil still. (Courtesy of Hacienda Anon, Ponce, P. R.)

coil in the bottom of the still pot. This procedure is referred to as open steam distillation and is considered to be the best distillation practice.

Haines (*35*) found that distillation with steam under pressure was more efficient than without pressure and that the poorest practice was to use direct firing. He recommended that the still pot be 2 to 2.5 times as high as in diameter and that it be lagged to decrease heat losses. Wilbaux (*72*) compared distillation from a still heated by direct fire with that from a steam-heated still pot with no water present. With the former method he obtained 0.29 percent yield of oil and with the latter 0.38 percent.

Detail of a modern distillery is shown in figure 9. In the left upper foreground the insulated steam pipe is shown; this leads to a valve and an automatic reducing valve and gage; from here the steam goes through a rubber hose to the bottom of the still pot. This is the large white vat shown partly inverted, mounted on trunnions and insulated with asbestos. It is made of copper three-sixteenths inch thick and tinned inside. The 750-gallon vat holds 1,500 to 2,000 pounds of chopped grass. By means of the wheel and gear the still pot can be inverted to empty the spent material. At the angle shown most of the charge is removed. The spent grass is received on a wagon for removal or placed on a belt leading to a dryer. On the upper opening of the still pot a gooseneck is clamped and connected by means of a union to the multitubular condenser shown below and parallel to the white steam pipe. Here the steam and oil vapors condense and pass to the cooler below, from which they pass to the separators. In the upper left are shown the vent condenser, safety device, and the tank for storage of hot water from the condenser. In the lower right is a vat into which the water passes after separation of the oil. Be-

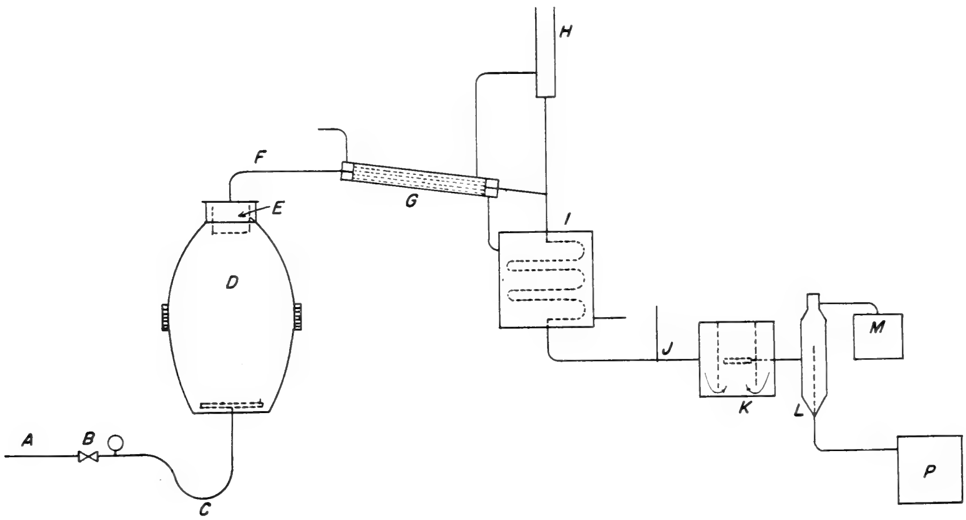

FIGURE 10.—Line sketch of the still.

cause this water contains some oil, it is recharged into the still with the next charge of grass.

In figure 10 is shown a line sketch of the still. Steam enters through insulated pipe, *A*, and passes through a valve and automatic reducing valve at *B* which lowers the pressure from that in the boiler to any desired operating pressure. A gage is placed after the valve. The steam then passes through a rubber hose, *C*, to the bottom of the still pot, *D*, where it is dispersed through a coil with appropriate holes. The still pot is mounted on trunnions so that after disconnection at the top, it can be inverted by means of a geared hand wheel to discharge spent plant material. To pass from the still pot to the condenser, the vapors must first pass through a perforated basket at *E*, which serves to filter grass particles from the vapors and thereby obviate fouling of the condenser.

The gooseneck *F* is clamped on the still pot and connected by means of a union to the 4-inch pipe leading to the condenser, *G*. This is a multitubular horizontal condenser. It consists of a 6-inch tube 8 feet long in which are mounted four 1¼-inch tubes about ½ inch apart. These small tubes are joined to the butt plates and lead to a common chamber at each end. Cold water from the cooler, *I*, below enters the right end of the condenser, *G*, and passes through the small tubes to the left end at which time it is very hot, and is conducted to a large storage tank from which hot water is drawn for the boiler and for charging the still. Condenser, *G*, is inclined slightly so that the liquid condensed at the left end will run toward the right end. Above the condenser is a device to remove uncondensable gases. Such gases, mostly air, are always present in the plant material and are entrained with the vapors. If not removed they will cause bumping and gushing upon bubbling through the separators. Since the separators should operate smoothly without gushing and mixing of the layers, it is highly desirable to vent out the uncondensable gases from the condenser. Any gases not condensed in *G* rise to the upper part of *H*, and any entrained condensables condense therein and run to the cooler, *I*. The gases go to the lower part of *H* and then are vented out of the system. The cooling water in condenser *H* flows to cooler *I*, and thence to condenser *G*. To cooler *I* flow the hot liquids from the main condenser and from the vent condenser. This unit consists of a serpentine cooler in which the hot liquids flow through a helix immersed in running water. From *I*, the water-oil mixture passes through a ¾-inch pipe to trap *J* which may be a T-tube open at the top to prevent siphon action between the separator and the cooler.

The mixture next passes to the oil-water separator, *K*. This unit is full of water during operation and the lighter-than-water oil rises while that heavier than water descends. (This latter is not present in lemon-grass oil.) The mixture enters at the center of the unit, and, in order for the excess water to escape, it must go down following the arrow around a cylindrical baffle. This cylindrical chamber separated by the baffle is accessible only from the bottom so that oil cannot enter from the top. The device is so constructed that the cross-sectional area of the outer cylindrical chamber is equal to that of the inner chamber to insure even velocity of water passing under the baffle. The major part of the oil is removed from the upper part of *K*. From the inner chamber the water, containing small amounts of oil, passes through orifices in an annular ring and thence to trap *L*. In this trap the height of the water outlet tube can be adjusted and this, in turn, determines the height of the oil-water interface in the upper chamber of *K*. By varying *L* the oil without any water can be drained from it at an even rate into the product chamber *M*. From *L* the water, still containing a small amount of oil goes to *P*, which is equipped with a sightglass. This water is pumped into the still pot with fresh grass and thus no oil is lost because of the incomplete separation of the oil-water distillate. Steam pumps should be utilized to pump water to the still pot and to the boiler.

Simplification of the apparatus shown in figures 9 and 10 would not necessarily lead to increased efficiency. One suggestion often made is that a water-sealed still head be used instead of one clamped on with wing nuts. A water seal is effected by setting the circular base of the still head in a trough of water which forms a collar on the still pot. This procedure has two disadvantages. First, the apparatus cannot be operated with pressure in the still pot. This may be satisfactory for some essential oils, but, in general, in making the investment necessary for equipment, it is best to provide for versatility. Later, vetiver root or a similar material which requires pressure may be available for distillation. The second disadvantage is that there is always some condensation on the still head which results in the oil going back to the still pot where it must be vaporized again. If such condensation is partly avoided by insulating the head, the device becomes more bulky. On the other hand, the still head can be used to advantage as a partial condenser. For this a tapered cone is used.

The taper of the cone should be such that any liquid condensing on it will run down the cone rather than back into the still pot. Near the base of the cone there is a circular trough which conducts the liquid to the condenser outlet also near the base. The base is set in a moat of water so that vapors do not escape. Although this arrangement saves some condenser water, it still allows some condensate from below the trough to return to the still pot. The disadvantages of the clamped still head are that the gaskets are expensive and easily injured and the fasteners are often cross-threaded. These disadvantages are minimized by having a comparatively small opening in the still pot and providing a good fit of the bolts and the condenser connection.

Another part of the apparatus that can be modified is the condenser. Although other types of condensers will do the work, the multitubular type is the most efficient condenser and the serpentine is the most efficient cooler. The condenser itself can be mounted vertically but no advantage is gained by this. The horizontal position conserves head space, thus making it possible to mount the cooler and separator at a convenient height above the floor. The vent condenser could be replaced by a simple open tube, but here again the question of versatility should be considered; for other essential oils, the rate of distillation may be such that some uncondensed oil would be lost by passing up the tube.

The separator could also be simplified by using one or more florentine flasks which should be 20 inches or more in diameter to allow for a slow rate of liquid flow (*35*). These, of course, would be easier to clean than other types of flasks. Obviously, if a less efficient separator is used, cohobation becomes necessary. Joly (*39*) found that the use of cohobation in the steam distillation of lemon grass increased the yield of oil almost one-fourth. The cohobation device could be arranged to return the water continuously to the still pot through a water seal. This arrangement, however, would be useless if the still pot were operated under pressure.

Figure 11 shows the type of still pots used in Haiti and figure 12 shows a distillery at Clewiston, Fla.

Another item of equipment is a grass chopper. It was found that distillation of grass chopped into ¼-inch pieces gave better results than distillation of whole grass or grass ground in a hammer mill (*9*). The latter tended to pack and to cause the steam to be channeled through the pack; and the yield of oil when this method was used was about half that obtained by distillation of chopped grass. Figure 13 shows a feed cutter mounted to discharge cut grass directly into a still. Cut grass can be packed into the still pot at the rate of 100 pounds per 6 cubic feet. Another packing schedule calls for 2 pounds of grass per gallon capacity of the still pot. The chopper should be arranged at the unloading platform where grass is brought in from the field. After passing through the chopper, it is stored prior to distillation in bins which feed directly into the still

FIGURE 11.—Stills used in Haiti for the processing of lemon grass.

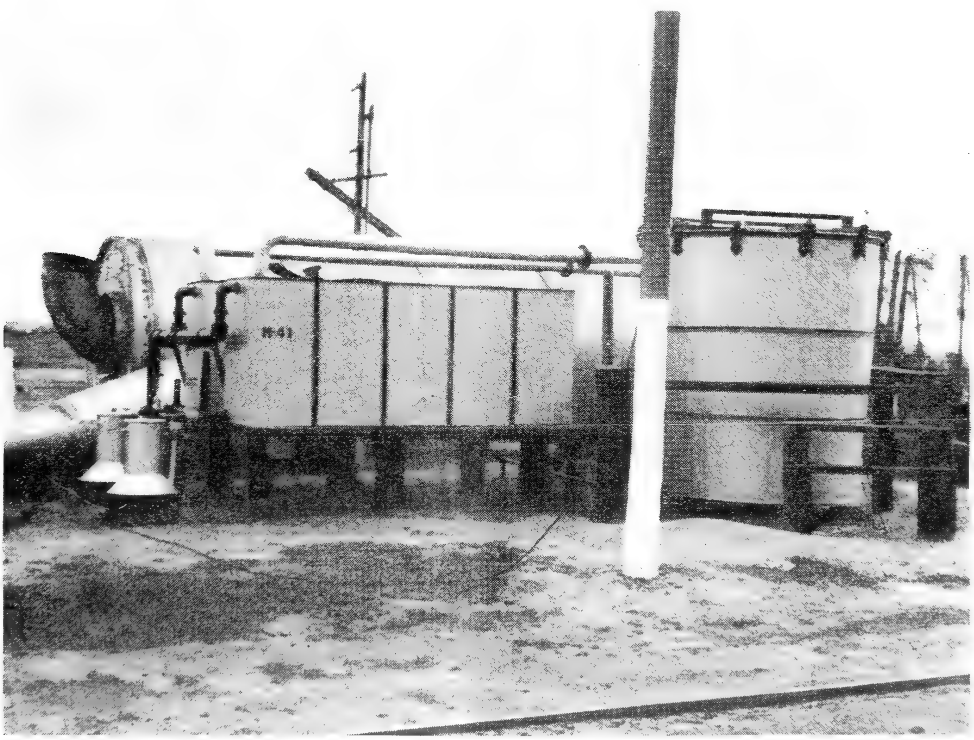

FIGURE 12.—Stills designed for processing lemon grass in Florida. Note the special receivers on the left for collecting the distillate and separating the oil from the water. The drying apparatus in the rear is used to dry the lemon-grass residue, which is then used in the preparation of cattle feed.

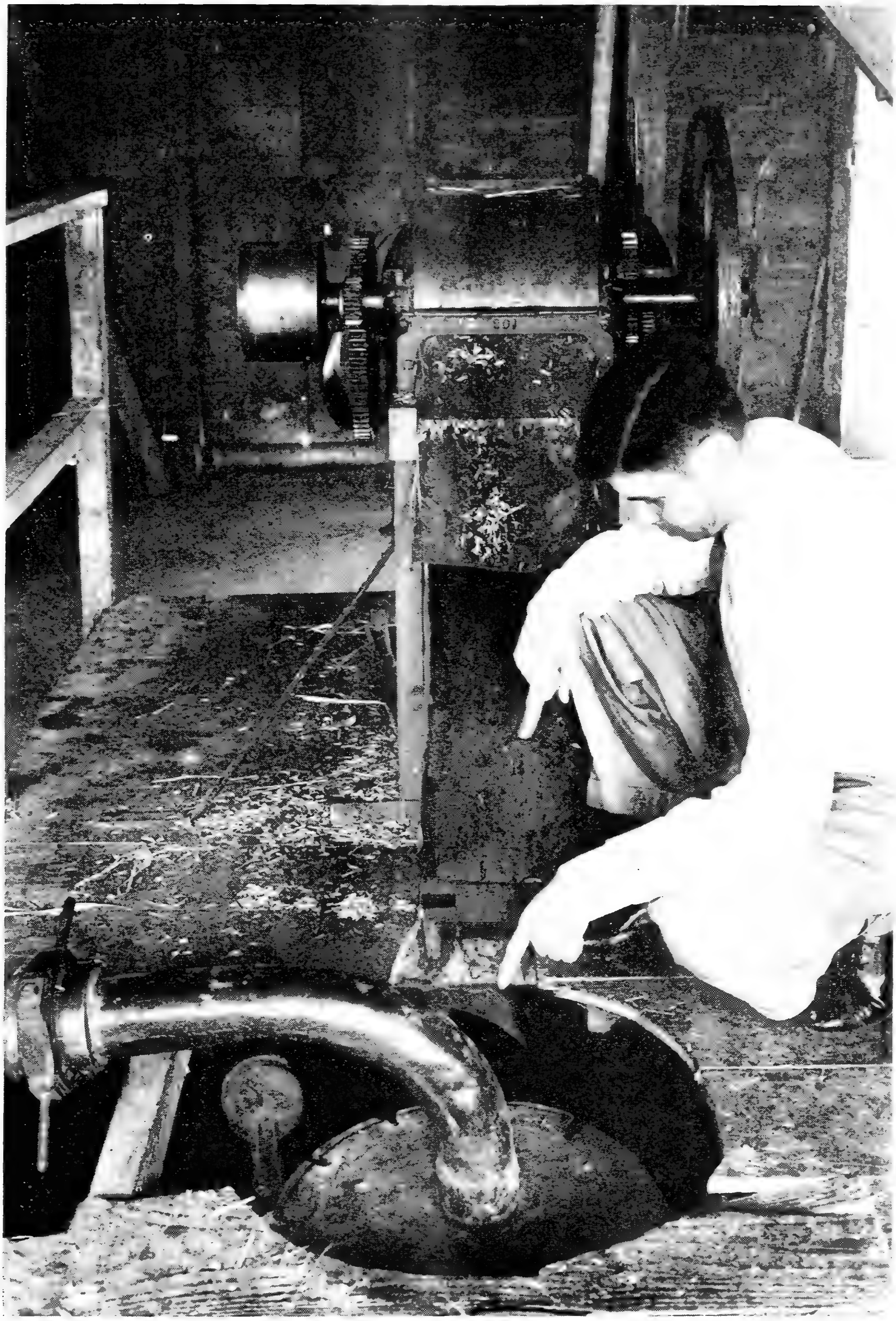

FIGURE 13.—Still head in Puerto Rico distillery. At right is feed cutter from which the cut grass goes directly into the still.

pot. In this manner the still is not kept out of operation while the charge is being chopped.

The choice of materials from which essential oil processing equipment can be fabricated is limited by the chemical reactivity of the oil (*7, 51*). The items of equipment whose metal parts affect the oil most are the distillation vessels and the containers in which the oil is stored after distillation. Klyuchevskii and Tenson (*5*) described the effect of several essential oils on various metals. They found that a special stainless steel EYa–1 and tin did not react with nor affect the oils; aluminum increased slightly in weight but did not change the oil. Copper, zinc, iron, and ordinary steel were corroded and discolored the oils. Bacon (*12*) recommended that the still pot be constructed of reinforced concrete but he did not state whether such construction had been tried. The most commonly used material is tinned copper.

DISTILLATION METHODS

In the steam distillation of lemon-grass oil from the grass, two processes occur. First, the oil is liberated from the plant tissue and then it is vaporized with the steam. Hence, before the oil can distill with the steam, it must be liberated from the plant tissue. The over-all rate of distillation of the oil from the grass will be determined by one of two factors—the rate at which the oil is liberated from the plant tissue or the rate of entrainment of the oil. This in turn is an important factor in the cost of production of lemon-grass oil, viz, overhead on equipment, labor to process, and fuel for the boiler. The capacity of the apparatus can be augmented by increasing its efficiency. Generally speaking, the slow step in the distillation of lemon-grass oil from the grass is the liberation of the oil from the grass. Hence, practices that increase the rate of entrainment are not so effective as would be expected. Nevertheless, it is well to provide for a sufficiently high entrainment rate in order to make certain that it does not limit the rate of the over-all process.

Any practice which would increase the rate of liberation of oil depends on breaking the cells or on cooking to force the oil out of the plant tissue. The breaking of the cell structure is accomplished by cutting the grass; the efficacy of this practice was pointed out in the discussion on equipment. The second method of increasing the rate of oil liberation consists of cooking the plant tissue (*13*). This is done by heating the charge, without removing the vapor, for a short time before distilling. The cooking can be effected at intervals by closing a valve between the still pot and the condenser.

In work at the Federal Experiment Station in Puerto Rico, 10-pound samples of lemon grass were distilled by two methods: (1) The ordinary procedure was used in which the grass is placed in the still pot and steam added while the valve to the condenser is closed. After 5 minutes the pressure in the still pot was 5 pounds per square inch; the condenser valve was opened, and distillation was carried on for 40 minutes. The average yield was 8.98 grams of oil containing 7.48 grams of citral. (2) The intermittent method was used; the steps in this procedure were the same as those in procedure 1 for the first 10 minutes, at which time the valve to the condenser was closed. After a period of 5 minutes, during which the pressure had increased to 5 pounds per square inch, the condenser valve was opened and distillation was resumed for 5 minutes.

This cycle of building up the pressure and distillation was then repeated; the pressure was then built up for 5 minutes and distillation resumed for 15 minutes. In this manner the over-all time was the same for the two methods. The average yield by the second method was 10.42 grams of oil containing 7.84 grams of citral. The yields by fractions showed that about half of the oil was distilled during the first 5 minutes of distillation. However, the oil which came over subsequently was so much richer in citral that more citral was distilled after the first 5 minutes. About 11 liters of water were distilled by the first method but only 8 liters were distilled by the intermittent procedure.

In another experiment, the two methods were compared in 1-hour distillations. The results were similar to the previous experiment; about 15 percent more oil was obtained by the intermittent method, and the oil contained 84 percent of citral as compared to 79 percent in the oil distilled by the ordinary method. The conclusion was that the intermittent method was the better because: (1) More oil could be distilled from the grass in a shorter time; (2) more citral was obtained, and (3) less water had to be distilled to carry over the oil. The end effect was to save fuel and time by increasing the over-all rate of processing. Whether this process of intermittent distillation would be so efficacious that the plant material need not be comminuted was not determined.

The rate of entrainment of oil by steam may be altered by changing the pressure in the still pot by means of a valve between the still pot and the condenser. Fritz (*31*) states that in Madagascar 500-gallon stills are operated at a pressure of 40 to 50 pounds per square inch to distill lemon-grass oil in 20 minutes. In Java a pressure of 15 to 20 pounds per square inch is often used to distill the oil from 110 pounds of grass per hour, but in Singapore practically no pressure over atmospheric is desired (*50*).

There is a choice as to the pressure to be maintained in the still pot. For lemon-grass oil, it may be calculated that passing steam at high pressure into the grass at low pressure gives the highest rate of entrainment. Thus, calculation shows that the rate of entrainment of citral per 100 pounds of water is 8.4 pounds when the distillation is carried out at ordinary pressure. Operating the still pot at a pressure of 69 pounds per square inch (150° C.) gives a rate of 16.5 pounds. Operating the still pot at ordinary pressure and injecting steam at 140 pounds pressure results in a temperature of 150.7° and a rate of 77.8 pounds of oil per 100 pounds of water. However, operating the still pot at 0.1 atmosphere pressure (76 mm.) and injecting steam at a pressure of 70 pounds per square inch results in a temperature of 116.6° and a rate of 189 pounds of oil per 100 pounds of water. To avoid operating under vacuum, it is therefore most practicable to operate the still pot at atmospheric pressure and to inject high-pressure (superheated) steam.

However, once the maximum feasible pressure is chosen for the boiler, the amount of steam should be adjusted so that it will be high enough to preclude the limiting of the over-all rate of oil recovery and yet not so high as to waste heat. It is important to note that the high rates of distillation discussed in the foregoing paragraphs are the theoretical maximum rates for the distillation of free citral; in practice, no such rates are realized. Actual rates of distillation are lower because: (1) The oil is not free in the still pot, and (2) a considerable amount of oil-water vapor condenses before reaching the highest point between the still pot and the condenser and runs back into the still pot. Additional steam is then required to distill the oil again.

In the Fiji Islands (*28*), lemon grass was distilled for 8 hours. Records were taken of the yield each hour. During the first hour, 37 percent of the oil came over; in the second hour, 24 percent; and in the third hour, 16 percent; and 5 more hours were required to obtain the remaining 23 percent. Russell (*57*) made a 1-hour distillation with a boiler pressure of 40 pounds per square inch to find that, during the first 20 minutes, 75 percent of the oil distilled; during the second 20 minutes, 15 percent; and during the last 20 minutes, 10 percent.

In a trial distillation at Mayaguez with water present in the still pot, a ratio of 1.1 pounds of oil per 100 pounds of water was obtained during the first 5 minutes. This rate decreased to an average of 0.3 pound during the next 35 minutes and to 0.1 pound during the next 55 minutes. In a large direct-heat still, the rate was 1.7 pounds during the first 5 minutes but averaged 0.54 pound per 100 pounds of water during 5 hours of distillation. The change in rate during distillation is brought about by two factors. First, the initial rate is high because the readily available oil is distilled during the first few minutes. Second, the more volatile fractions of the lemon-grass oil come over in the first distillate. After the more volatile part is out of the still pot, there remain the less volatile fractions, which require greater amounts of steam to distill.

The time required for a complete distillation, from charging the still pot to recharging it, is an important factor in the production of lemon-grass oil. This factor includes the time required to load, close, and heat the still pot, distill the oil, stop the process, and discharge the spent grass. If the still pot is rapidly loaded from a bin and unloaded by inverting or removing a basket, the greatest portion of the time will be utilized by actual distillation. Since the initial rate of distillation of oil is high but decreases as the process continues, it is most efficacious to change the rate of passage of steam during the distillation so that at first it is very great—more than enough steam to carry over all of the available oil. Then the rate can be tapered off to approach zero at the end of the distillation. However, the rate of steam passage should always be high enough to insure that the rate of liberation of oil from the grass is the slower step in the distillation process. If sufficient steam is not added the time during which oil is available for distillation will be wasted.

The capacity of the apparatus must be such that it will balance the amount of lemon grass and other essential-oil-bearing plant material produced. If the apparatus is too large, useless overhead costs will be incurred. As a rough guide, about 15 gallons of water should be distilled per hour per ton of charge; this requires about 5-horsepower boiler capacity per ton of grass in the charge. From experience with stills larger than the pilot size, it is estimated that a 20-horsepower boiler would be sufficient to run four still pots of 1-ton capacity (about 1,000 gallons). This is a conveniently small still pot; it can be mounted on trunnions for inversion to discharge the spent grass or, if baskets are used, they are small enough to be readily handled. With a 4-hour cycle for distillation, 24 tons of grass could be distilled every 24 hours. About 4 tons of wood for fuel would be required. If the apparatus were operated 300 days a year, 7,200 tons of grass would be distilled to yield about 50,000 pounds of oil. With 30 tons of lemon grass per acre per year, the stills could handle the product of 240 acres. With 5 men to run the stills each shift of 8 hours, the labor required would be approximately 1 man-hour per pound of essential oil.

The effects of adding salt to the plant material and water in the still pot were studied at the Federal station with particular reference to bay-oil distillation (*5*, *6*, *40*, *41*). The addition of salt was also tried in lemon-grass distillation (*53*). It was found that distillation of the grass from a 28-percent solution of sodium chloride increased the yield of oil by one-third. The salt solution could be used again while still hot (*70*). Whether this practice is feasible under any given conditions depends upon the economics of the situation.

The oil obtained from the receiver in the distillery is usually accompanied by small amounts of water. If great amounts are present, separation can be effected with a separatory funnel. Umney and Bunker (*69*) showed that wet lemon-grass oil on storage increased in density and refractivity while dry oil decreased in refractivity. Further work (*2*) showed that the wet oil decreases about 10 percent in aldehyde content during several months' storage. In several years even dry lemon-grass oil decreases in aldehyde content. Glichitch (*32*) showed that dry oil contained 0.1 percent of water and the oil saturated with water contained 2.8 percent of water. The oil is dried by mixing with anhydrous calcium chloride, sodium sulfate, or magnesium sulfate and filtering it through filter paper after it has had several hours' contact with the drying agent. It is then stored in well-filled air-tight containers in a dark, cool place. Figure 14 shows oil packaged for shipment in tinned containers. These containers should be tin-surfaced or glass since iron or copper discolors the oil. Kerosene and coconut oil are the most common adulterants used for lemon-grass oil; both are readily detected by the buyers.

In most producing areas fuel is an important consideration especially if the scale of operations is large. Haines (*35*) estimated that fuel costs amount to about one-half of the cost of production of lemon-grass oil in Seychelles and that air-drying of the wood used for fuel reduced the fuel requirements by 20 to 25 percent. Lagging of the still pot and boiler increased the amount of water distilled per unit of wood by 25 percent. Of the woods tried, the decreasing order of fuel value on a weight basis was as follows: Capucin (*Nathea seychellana*), coconut shell, cedar (*Casuarina equisetifolia*), acacia, agatte, and coconut husk. The last-named was about two-thirds as valuable for fuel as coconut shell. Under some circumstances an automatic boiler burning fuel oil may be feasible.

Usually, much wood can be obtained from removal of trees and from pruning of some tree crops. Also the lemon-grass residue discharged from the still pot can be dried and burned. Comparison of the fuel requirements with the amount of lemon-grass residue available shows that from one-third to one-half of the fuel could consist of exhausted lemon grass. It is important that the spent grass be dried to the greatest extent practicable or else much of its fuel value will be wasted in driving off the remaining water. It was shown at Mayaguez that the dry grass is roughly equivalent to pine and bamboo in calorific value.

For a general discussion of processing, the reader is referred to the recent work of Guenther (*33*).

FIGURE 14.—Citronella and lemon-grass oil ready for shipment.

THE COMPOSITION OF THE OIL

The oil as prepared for the market contains from 60 to 75 percent of citral. Umney and Bennet (*68*) demonstrated the difference between West Indian and East Indian lemon-grass oils. They distilled the oils to find that up to 210° C., 23 percent of the West Indian product distilled as compared to none of the East Indian oil. Kafuku (*43*) showed that myrcene was present in lemon-grass oil. He also found a small amount of an aldehyde other than citral (*44*). Elze (*25*) found methyl heptenol, nerol, and farnesol in the oil. In more extensive work, Naves (*49*) found diacetyl which remained in the distillate water. He estimated the oil contained 12 to 20 percent of myrcene, 1 percent of sesquiterpenes, 2 to 3 percent of diterpenes, 1 to 1.5 percent of alcohols, 0.2 to 0.3 percent of methyl heptenone, besides the 65 to 86 percent of *a* and *b* citral. He identified more than 20 other constituents.

The solubility of the oil in 70-percent alcohol is not considered important at the present time; this property appears to be a changing characteristic. Some authentic samples of fresh oil are soluble, but become insoluble after some weeks of storage as a result of oxidation and polymerization. The citral content is the important criterion because it is extracted and used as a raw material in the synthetic chemical industry.

Citral, $C_{10}H_{16}O$, is a mixture of a *cis*-isomer, citral *a*, geranial, and a *trans*-isomer, citral *b*, neral, each of which consists of a mixture of two structural isomers (*34, vol. 2, pp. 326–327; 65, p. 88*). It is the terpenic aldehyde responsible for the characteristic odor of lemon-grass, lemon, and verbena oils. The chief commercial source at present is lemon-grass oil. Citral is used to some extent in perfumes to which it imparts a fresh, desirable aroma, but its principal importance to the perfumer is as the raw material from which ionone and similar artificial violet perfume can be manufactured. At atmospheric pressure citral boils at 228° to 230° C. with some decomposition, and at 12 millimeters pressure, at 110° to 112°. It has a specific gravity of 0.893 at 15° and a refractive index at 17° of 1.49015. It is optically inactive. Citral may be extracted from lemon-grass oil as a bisulfite compound. In this method lemon-grass oil is shaken for several hours with a concentrated solution of sodium bisulfite while the mixture is kept slightly alkaline. The white frothy solid which forms is drained and pressed between folds of absorbent paper. The citral is liberated from the solid by soda. A better method to obtain citral from lemon-grass oil, according to Sorges (*66*), is to fractionate under reduced pressure. This process can be carried out by fractionation of separate lots or in a continuous column in which the oil is added and the fractions removed continuously (*59*).

Ionone prepared from citral is one of the most important ketones used in the preparation of violet odors for perfumery. Commercial ionone, which is a mixture of *a*- and *b*-ionones, has a powerful, numbing aroma which does not resemble the sweet, natural aroma of violets. However, upon dilution with alcohol, it has a pleasing, fresh, flowery aroma recalling natural violets. In addition to its use in perfumery, it is sometimes used in certain confectioneries and liqueurs. Only a small quantity is necessary to give the characteristic tone to violet preparations.

Ionone is either made directly from lemon-grass oil or from citral. Pseudoionone results from the condensation of equal parts of citral and acetone in the presence of an alkali like barium hydroxide. It may be used as raw material for perfumes, or first changed into its isomer, ionone, by heating with dilute sulfuric acid and a little glycerine.

ECONOMIC CONSIDERATIONS

A description of the production and processing of lemon-grass oil is given in this publication. The best cultural methods are suggested. However, there remains the inevitable question that occurs to the prospective producer: "Can I produce lemon-grass oil profitably?" This query can be intelligently answered only by the prospective producer after considering the facts and his own conditions. On the economic side of the question, the cost of production must be estimated. The possibility of producing lemon-grass oil along with other essential oils to make maximum use of distillation equipment deserves consideration. The bulk of the lemon grass distillation on a small or medium scale will be done during the wet season when the grass is growing rapidly. During the dry season, bay leaves or material from a similar essential-oil-bearing plant that can be harvested during the dry season may be distilled.

Figures reported from Jamaica give the following breakdown of the cost of various operations in terms of percentage of the total cost of production of citronella: Plowing and harvesting, 8; preparation of plants and planting, 16; forking and weeding, 45; cutting and weighing, 10; cutting wood for fuel, 6; and attending still, 15 percent (*38*). Although these data were recorded in connection with citronella culture they should be roughly applicable to lemon grass. Fabris (*26*) reported corresponding cost data on the culture and distillation of lemon grass in Somaliland as follows: Grass, 50 percent; handling, 13; fuel, 25; overhead, 12. The cost of the lemon-grass oil was about $0.68 per pound under his conditions. In 1919 Russell (*57*) gave cost figures for lemon-grass production in Florida. They were on an acre basis; for the first year, plowing $3; planting, $2; cultivation, $2; harvesting and distilling, $3.40; for the second year, fertilizing, $4.50; cultivation, $1.50; harvesting and distilling, $7; and for the third year, cultivation $1.50; harvesting and distilling, $4.65. The total cost for the 3 years was $29.55, whereas the income from the sale of the oil was $68.81, making a net profit of $13.05 per acre per year.

Lemon grass can be planted and grown for about 400 man-hours per acre per year. For harvest (not mechanized) 25 man-hours per acre per harvest may be allowed; at 4 harvests per year this totals 100 man-hours. An additional 100 man-hours for transportation and chopping, and 200 man-hours per acre may be allowed for the processing of the grass to obtain the oil. The total man-hours expended per acre per year, therefore, is 800. The annual return per acre in the Tropics may be estimated at 200 pounds of lemon-grass oil if soils and water are adequate. This is at the rate of 4 man-hours per pound of oil. If an overhead of 5 cents per pound of oil is allowed, the calculated profit per pound is the value of the oil per pound minus the value of 4 man-hours and the overhead of 5 cents. The profit per acre is 200 times that. Thus, if in the producing area, a man-hour is worth 10 cents, the cost of production of the oil would be 45 cents per pound. At that cost of production, a profit of 20 cents per pound or $40 per acre per year would be realized when the selling price is 65 cents per pound.

An additional income can be gained if the exhausted grass can be sold or used as a cattle feed. Cattle eat the grass readily if salt is on the residue as is the case when salt is used in the distillation. An analysis of lemon-grass residue made at this station by Carrero is given in table 7.

The table shows that as a feed the residue is approximately equivalent to other grasses. For the preparation of a feed, the spent grass is dried in the sun or in a rotary dryer and ground to a powder. It is then mixed with amendments such as molasses and soy proteins. Bourne (*14*) and Bourne and Nielsen (*17*, *18*) have shown that an excellent finishing feed can be prepared with lemon-grass residue as the basic component. Hill (*36*) reports that in a dry-lot feeding project in Florida, cattle were fed a dried lemon-grass composition mixed with

TABLE 7.—*Composition of lemon grass after removal of the oil by steam distillation*

Sample Number [1]	Ether extract	Crude fiber	Sugars			Moisture	Total ash	Silica (SiO_2)	Phosphorus (P_2O_5)	Lime (CaO)	Magnesia (MgO)	Nitrogen	Crude protein
			Invert	Sucrose	Total								
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
A	0. 82	7. 53	1. 09	1. 17	2. 26	70. 00	1. 93	0. 94	0. 17	1. 10	1. 40	0. 110	0. 690
B	. 44	4. 41	. 87	. 57	1. 44	81. 06	1. 15	. 59	. 10	. 64	. 81	. 065	. 407
C	. 43	5. 03	. 72	. 54	1. 25	81. 02	1. 09	. 63	. 09	. 59	. 73	. 061	. 381
D	. 44	4. 70	. 67	. 44	1. 11	70. 04	3. 30	. 62	. 07	. 52	. 54	. 063	. 393
DRY BASIS													
A	2. 73	25. 09	3. 64	3. 91	7. 55	None	6. 42	3. 12	0. 55	3. 68	4. 67	0. 367	2. 30
B	2. 32	23. 26	4. 61	2. 99	7. 60	None	6. 06	3. 08	. 52	3. 40	4. 29	. 344	2. 15
C	2. 28	26. 49	3. 77	2. 83	6. 60	None	5. 73	3. 25	. 47	3. 12	3. 85	. 322	2. 01
D	2. 11	22. 45	3. 20	2. 09	5. 28	None	15. 73	2. 98	. 35	2. 49	2. 56	. 300	1. 87
AIR-DRY BASIS (7.8-PERCENT MOISTURE)													
A	2. 52	23. 14	3. 36	3. 61	6. 96	None	5. 92	2. 83	0. 51	3. 39	4. 31	0. 388	2. 12
B	2. 14	21. 45	4. 25	2. 76	7. 01	None	5. 59	2. 84	. 48	3. 14	2. 90	. 317	1. 98
C	2. 10	24. 43	3. 48	2. 61	6. 09	None	5. 28	3. 00	. 48	2. 88	3. 55	. 297	1. 85
D	1. 95	20. 70	2. 95	1. 93	4. 87	None	5. 30	2. 75	. 32	2. 30	2. 36	. 277	1. 73
Napier-grass hay [2]	1. 8	34. 00				10. 09						1. 31	8. 20
Para-grass hay [2]	. 9	33. 60				9. 8			. 16	. 42		. 74	4. 60
Sorghum bagasse [2]	1. 4	31. 3				10. 7						. 50	3. 10
Velvetbean hay [2]	3. 1	27. 5				7. 20			. 24			2. 62	16. 40

[1] Sample A was fresh; sample B had been subjected to steam distillation; sample C had been subjected to distillation immersed in water; and sample D had been subjected to distillation immersed in 2N NaCl solution.

[2] MORRISON, F. B. FEEDS AND FEEDING. Ed. 20, pp. 960, 962, 964. Ithaca, N. Y. 1936.

molasses. To this mixture was added one-sixth part of a protein supplement consisting of cottonseed, peanut, or soybean meal. Although no grain was included in the ration, the meat from the animals fed this ration was of good quality and the average gain per head was satisfactory. The value of the pulp was estimated at $6 per ton although it would probably be worth much more in the Tropics. At this rate the 30-ton yield per acre of fresh grass would amount to about 6 tons of dry residue worth $36. This additional income would increase the profit per acre to $76. These estimates are, of course, approximate. The cost figures would vary considerably under different operating conditions.

If labor is high, the crop must be handled mechanically. Even with mechanization, Bourne (*14*) reports that a loss was sustained in Florida production. He reports the cost of production as $1.80 per pound but this was high because of poor yields and the high cost of labor which was generally more than $4 a day. With some mechanization and the lower labor costs and higher yields obtainable in the Tropics, the cost of production of the oil is much lower. There is also the likelihood of improvement in production methods. If plant breeding and selection, as well as field experiments with fertilizers, irrigation, and other factors were carried out with lemon grass, it is possible that improvements could be made just as has been done in the breeding and raising of sugarcane. The only practically competitive crop as a source of citral is the Australian eucalyptus, *Backhousia citriodora* F. Muell. Bacon (*12*) points out that the oil distilled from the leaves of this tree contains 10 to 20 percent more citral than does lemon-oil grass. Since the eucalyptus is a tree crop it is probably a costlier source of citral than lemon grass. The possibility of lemon-grass oil maintaining a place on the market should not be overlooked. Although some other crops are becoming less important, lemon-grass oil appears to remain in demand because of its value as a cheap chemical raw material.

SUMMARY

(1) The essential oil distilled from lemon grass is produced mostly in the Tropics at an annual rate approaching 1 million pounds; the price has varied from 28 cents to $4.50 per pound on the New York market.

(2) The grass is propagated by division of stools and planted 4 bud pieces to a hill every 2 feet in rows 3 feet apart. Planting is best done during the rainy season.

(3) A well-drained soil is desirable and the grass can be grown on hillsides as a soil-conserving grass.

(4) Lemon grass responds to fertilization with compost, manure, nitrogen, and potash.

(5) No shade should be used for lemon grass.

(6) The grass, which can be harvested by hand cutting or mechanical appliances, yields at the rate of 20 to 50 tons per acre per year.

(7) The grass is best cut about 4 times a year at a height of 2½ to 3½ feet.

(8) The fresh grass is chopped and steam distilled to obtain the oil. Best results are obtained by passing high-pressure steam into

the mixture of grass and water. The rate of distillation can be increased by building up pressure in the still pot at intervals.

(9) The oil is stored in glass or tinned containers and sold to manufacturers for use, as such, in low-priced soaps or to extract the citral for use as a chemical raw material.

(10) The residue from the distillation can be used as a cattle feed or fuel.

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